The story of the turbojet origins

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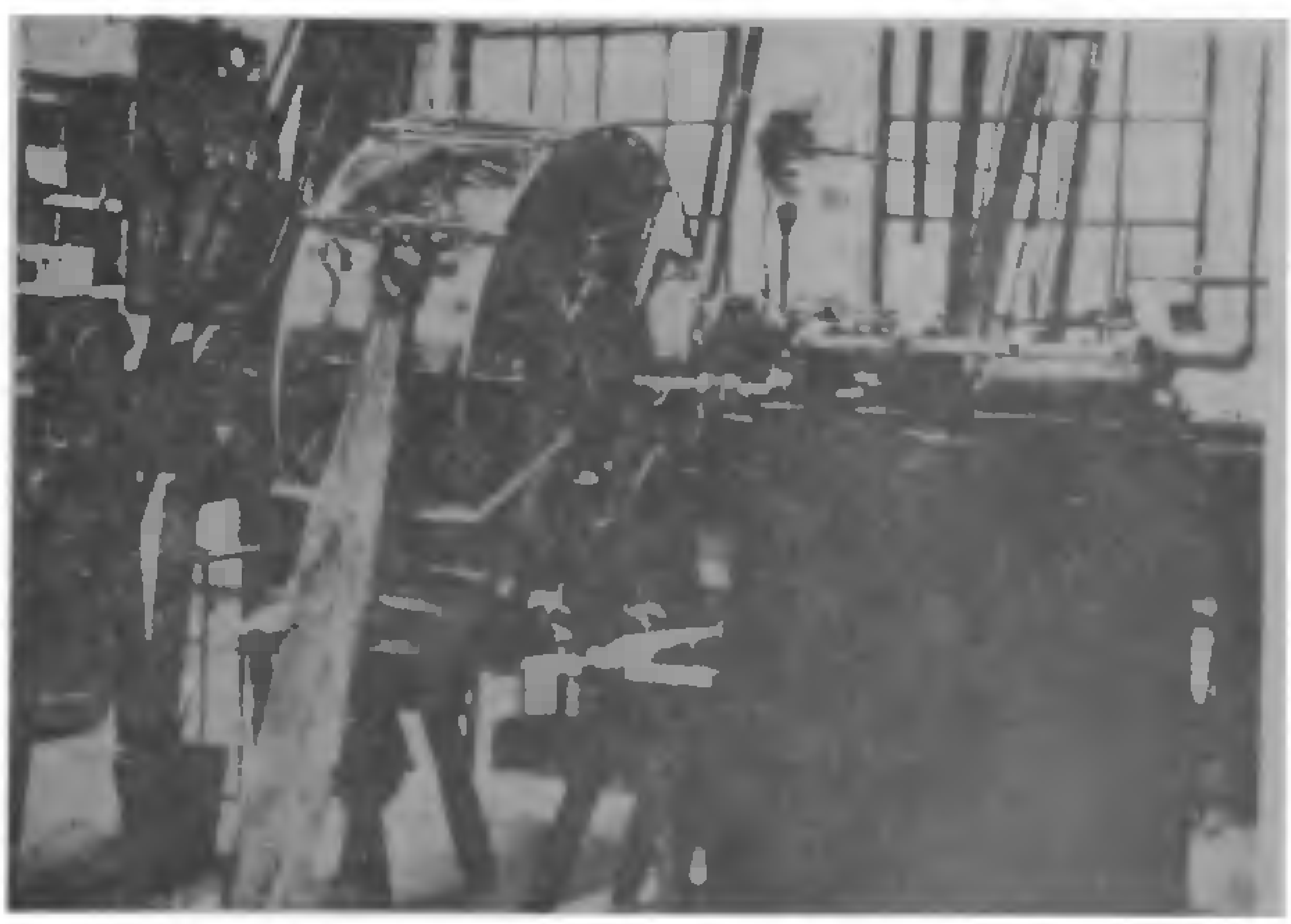
As we sip our coffee placidly, looking at the cotton wool clouds down below, cruising at a height of 11 km and with the comforting whine of the turbojet engines pushing us forward at an imperceptible 850 kmph, it is hard to realize that just 52 years ago, this was a mere dream. A dream, which a few individuals working with inspiration and in scientific pursuit, independently brought to the realms of reality—a propulsion device light enough to be airborne and highly efficient at high speeds of the order of the speed of sound. Foremost among them were Frank Whittle in England and Hans von Ohain in Germany, who arrived at the turbojet as the solution for high speed flight and more importantly, by singular pursuit were able to transform the idea to a practical realization leading to a revolution in aviation over a short span of a few decades.

The story of the original development of the turbojet is a fascinating one: the events in England and Germany happened at more or less the same period between late 1920s and early 1940s. During this period, aviation was a nascent subject and rapid progress was being made in the fields of aerodynamics, aircraft structures, propulsion systems namely reciprocating engines and propellers, leading to improved performance and reliability. For instance, in the twenties, the airframes were invariably of wooden frame construction with fabric covering. The breakthrough was the use of monocoque construction using aluminium alloys-skin which were load-bearing elements. This led to a dramatic increase in the strength of the structures besides permitting more stream-lined construction. It was realized at that time that with this form of construction, much higher speeds could be achieved with an efficient propulsion system for high speed flight. Also, the limitations of the propeller driven by piston engines were realized. In particular a drop of efficiency of the propeller at high speeds due to the onset of compressibility effects was seen as a limiting factor for such propulsion systems. Though impressive speed records were achieved in international races: for example 509 kmph (318 mph) was achieved in the Schneider trophy race of 1928 and a record of 570 kmph (357 mph) was set in 1929, it was realized that though the horse power requirement of the propeller went up steeply, the gain in speed was marginal. Moreover the life expectancy of such engines was hardly a few hours. Thus, the quest for an efficient power plant for high speed flight which would not have the drawbacks of the piston engine and the propeller occupied the creative minds of several engineers and technologists of the time.

Frank Whittle in England was one such person who was totally fascinated by the challenges of high speed flight. While still in college, he wrote an article for his college magazine in 1928 which projected an important realization that to achieve high speeds and long range, it would be necessary to fly at very high altitude where the low air density would substantially reduce the resistance, thus permitting higher speeds. He realized that the conventional piston engine was limited by the supercharger efficiency and that propeller performance would deteriorate due to compressibility effects and onset of shockwaves. Moreover, he also discerned that while rocket propulsion was a suitable propulsive device for high speed flight, its propulsive efficiency for the speed range around 500 kmph (300 mph) would be very unsatisfactory. Pondering over these questions, he felt the answers lay in utilizing a high speed turbine and a reaction jet in some combination. In the following year, he came up with the idea of a piston engine driven fan located in a duct with provision for burning fuel downstream of the fan to increase the jet thrust. However, given the weight of the piston engine and propeller system he soon realized that such a combination may not be superior to the then conventional propulsion systems. This led him back to the notion of the gas turbine and its advantages for high speed flight. In his words:

"While at Whittering, it suddenly occurred to me to substitute a turbine for the piston



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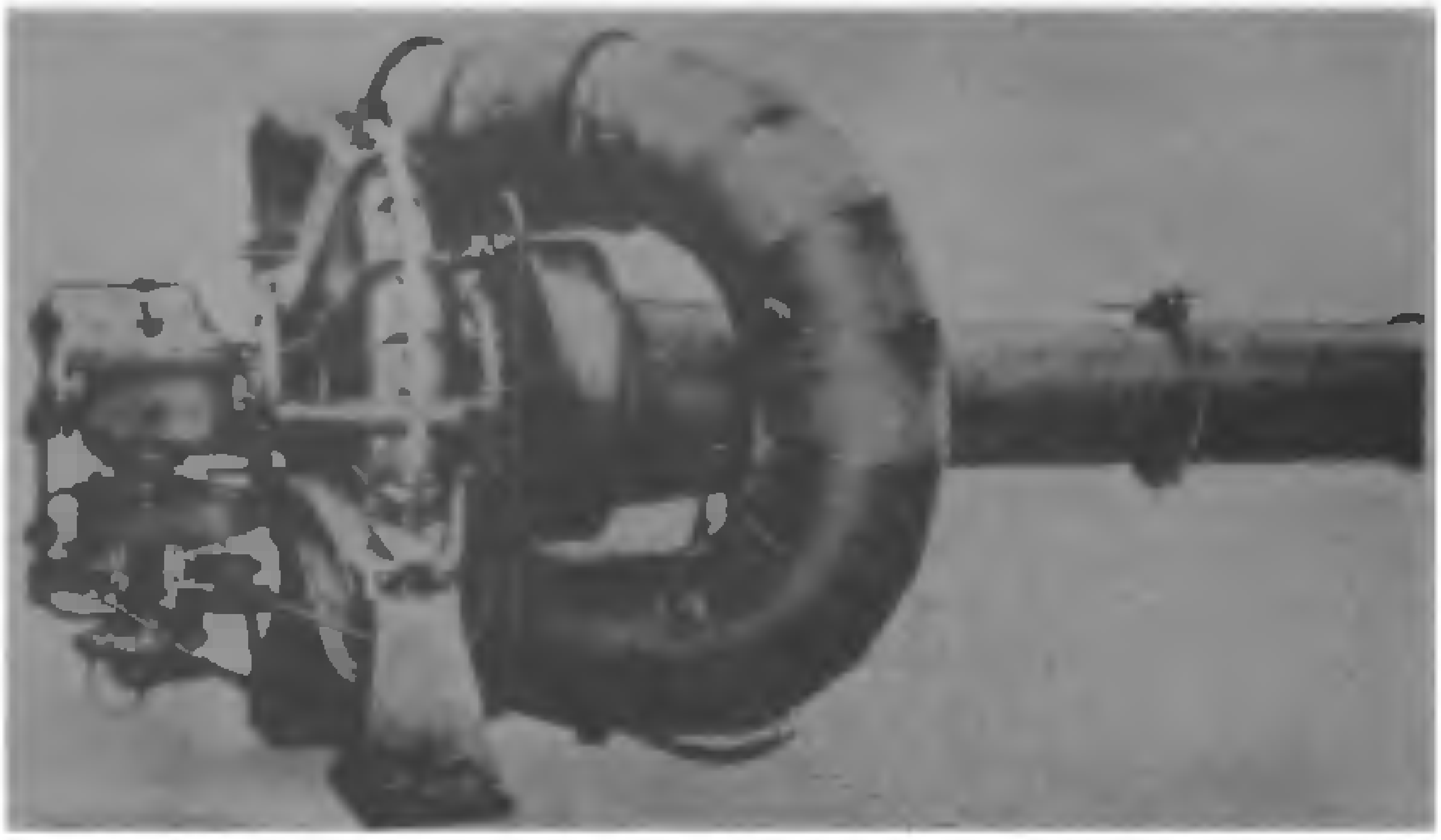
von Ohain's first demonstration turbojet



Whittle's W U turbojet

engine (in the ducted fan system). This change meant that the compressor would have to have a much higher pressure ratio than the one I had visualized for the piston engined scheme. In short, I was back to the gas turbine, but this time of a type which produced a propelling jet instead of driving a propeller. Once the idea had taken shape, it seemed rather odd that I had taken so long to arrive at a concept which had become very obvious and of extraordinary simplicity. My calculations satisfied me that it was far superior to my earlier proposals."

Thus Whittle's idea of using the jet thrust of the gas turbine exhaust directly for propulsion makes a distinct departure from the concept of using a gas turbine to drive a propeller in a turbo-prop engine. It is interesting to note that the gas turbine as a means of ground-based power generation was well known at that time, though it was not particularly successful or widely prevalent. As far back as 1907, Armegaud and Lemale in France had developed an elaborate combustion turbine system which was successful in the sense that it gave a positive power output, albeit at a low efficiency. Moreover it was very bulky and used about 25 impellers to attain a pressure ratio of 3:1. The fuel consumption was about four times higher than a contemporary piston engine. Thus the gas turbine was by no means a technological success of the time and to think of it as a means for aircraft propulsion was very far fetched indeed. In fact, Whittle had to use for his calculations, values of component efficiencies far higher than those achieved at the time, in order to demonstrate on paper, the feasibility of jet propulsion. His master stroke was the use of the jet thrust for propulsion. This implied that the turbine would need to develop only enough power to drive the compressor and nothing more. The propulsive force would issue from the reaction of the exhaust gases expanding through a nozzle. Nevertheless, Whittle's efforts to translate his convictions of what was possible into a reality is a remarkable story of determination and perseverance against several odds. It also brings out the deficiencies of a bureaucratic, state controlled R&D system in accepting a new idea with great potential, particularly at the initial stage of development.

Thus, when Whittle explained his concepts and calculations to A. A. Griffith of the Air Ministry, he was snubbed and told that his idea was not workable because of the efficiencies of the components assumed being too optimistic and due to limitations of materials temperature and stresses. Undaunted by this event, Whittle proceeded to apply for a patent in January 1930 and the patent was subsequently granted. Whittle was at this time with the RAF, undergoing various training courses. In 1932, he was posted to the Officers Engineering Course at Henlow and as a special measure he joined Cambridge University in 1934 to do his Tripos in Mechanical Sciences which he did in record time. Meanwhile, his turbojet patent came up for renewal and it is ironical that he let it lapse as he did not have a spare £ 5 required for its renewal! Whittle had a very difficult time in persuading someone to support him financially for an undertaking to develop a prototype of his turbojet. Finally, he managed to obtain funding from an investment banking firm to launch a small company, 'Power Jets' with an anticipated expenditure of £50,000. At this time, Whittle was a graduate student at Cambridge on deputation from the Air Ministry and it is interesting to note that the Ministry let him spent an extra year at Cambridge to work on the engine.

Power Jets, working on a shoe-string budget, had to contract out the component fabrication of the Whittle engine. The actual development began in 1936 with contracts to the British Thompson Houston at Rugby. The first Whittle engine was configured around a double-sided centrifugal compressor of 483 mm (19 inches) diameter, with a design efficiency of 80 per cent and a pressure ratio of 4:1. A vaneless diffuser was used to decelerate the flow from the impeller and into a single combustion chamber where atomized gasoline was burnt. The products of combustion were expanded through a single stage axial flow turbine of 406 mm (16 inches) diameter. The engine was designed to produce a propulsive thrust of about 6.2 kN (1400 lb) while flying at 800 km ph (500 mph) at 21.3 km (70,000 ft) altitude. To achieve this, the turbine would have to produce 2240 kW (3000 hp) to drive the centrifugal compressor: a very high power density by any of the existing standards. Ironically, a major developmental problem faced by Whittle was the combustion system development. The combustion intensity in the proposed engine was about twenty times greater than contemporary industrial standards and to obtain a workable system was extremely difficult. One major handicap was that there were no adequate facilities to test each component independently. Rather, the complete engine was built and operated, which made identification and solution of mismatch and component problems very difficult. The engine was first run successfully on 12 April 1937. Whittle was able to influence the Air Ministry to undertake a review of the possibilities of turbojet propulsion and to give a small contract to Power Jets. Still on a shoe-string budget, the engine went through a series of failures, rebuilds and modifications and, of course, improvements.

A major milestone was a demonstration of the running engine to the top brass of the Air Ministry who thereafter moved quickly: Power Jets was given a contract in July 1939 for a flight engine, the W.1 and the Gloster Aircraft a contract for an experimental airframe. Moreover, the Royal Aircraft Establishment changed course and opted in September 1939 for the development of a turbojet engine in preference to its earlier commitment to the development of a turbo-prop engine. Thus, Whittle achieved a breakthrough in converting sceptics of his time into strong believers of turbojet propulsion by his tenacity, application of scientific principles and engineering skills. After getting the full support of the establishment and overcoming the remaining technical problem namely the combustor problem, the first test flight of the Gloster E 28/39 powered by the W.1 took place on 15 May 1941. This W.1 engine developed a maximum 4.45 kN (1000 lb) thrust at 17,000 rpm and had a specific fuel consumption of 1.4 lb of fuel per lb of thrust. The ultimate maximum test speed of the E 28/39 aircraft was 592 kmph (370 mph) at 7.6 km (25,000 ft), a significant increase over the contemporary piston-engined aircraft.

We now leave the shores of England to Germany, where the quest for efficient, high speed flight was occupying the minds of several talented technologists and scientists. Given the political climate of the period it is not difficult to imagine that each person was following his own line of thought and was not aware of similar activities going on elsewhere. Thus, Hans J. P. von Ohain, a young doctoral student in Physics at Göttingen University was fascinated by the challenge of flight at high speeds and we totally unaware of the work by Whittle going on in England. Yet, the solution which Ohain arrived at was remarkably similar.

Von Ohain was convinced that to achieve speeds higher than 480 kmph (300 mph), a form of propulsion other than the piston engine and propeller was required. He felt that a continuous aerothermodynamic propulsion process could be inherently more powerful, smoother, lighter and more compatible with the aerovehicle than a propeller piston engine. In his words,

> "In the fall of 1933, my thoughts began to focus on a steady aerothermodynamic flow process in which the energy for compressing the fresh air would be extracted from the expanding exhaust gas. Such a steady flow process promised a far greater air volume handling capability than that of a reciprocating engine and consequently a much greater power concentration and power-to-weight ratio. Also, the air ducted into such a system could be decelerated prior to reaching any Mach number-sensitive engine components. Both of these characteristics are of great significance for a high speed propulsion system.
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> Searching for an extremely light weight, compact and simple configuration having a minimum development rise; I chose a radial outflow compressor rotor back-to-back with a radial inflow turbine rotor. This configuration also promised correct matching simply by providing equal outer diameters for the straight radial outflow compressor rotor and the straight radial in-flow turbine rotor. I was aware of the possibility of employing axial flow compressors and turbines and I considered an axial flow configuration as very desirable for future developments from a stand point of small frontal area, but as too complex and expensive for the beginning. In particular, stage matching of a multistage axial flow compressor and matching of axial compressor and turbine without component test facilities appeared to me too risky."

Going ahead on this premise, von Ohain filed a patent and proceeded to construct a small working engine with his own funds. Spending just over a thousand marks, he fabricated a small turbojet engine in the automobile workshop of his acquaintance Max Hahn in Göttingen in 1935. The engine gave him valuable experience and encouragement, though it never really ran. He had problems in obtaining satisfactory combustion in the engine and he also realized that the full scale engine development was beyond his personal financial means.

He approached, through his professor at the University, Ernst Heinkel— an enthusiast for high speed aircraft and a renowned aircraft-builder. Heinkel was favourably disposed to the idea and offered employment to von Ohain and Max Hahn to work on developing a turbojet engine. He also put them in touch with his ace aircraft designers and gave them a small place to work at Marieneche. Work on a demonstrator engine commenced in April 1936 and the engine had its first run in less than a year's time, late February or early March 1937, about the same time that the Whittle engine first ran. In view of his earlier problems with combustion of gasoline in his small working model, von Ohain chose hydrogen as the fuel for his demonstrator engine. This was a very apt choice since it being a highly reactive gas avoided any combustion problem and the development of a combustor operating on liquid fuel could proceed side by side. This approach gave an advantage of about two years to von Ohain over Whittle who had chosen the gasoline burning combustor in his prototype engine. Von Ohain's demonstrator engine produced about 2.5 kN (550 lb) thrust and enthused Heinkel to immediately sanction the building of a flight engine and an airframe, the He 178. The first flight engine, which was similar to the demonstrator engine, except for an additional axial fan stage preceding the centrifugal compressor, was tested in 1938. As it did not develop the required thrust, it was redesigned and rebuilt as He S-3B. The experimental airframe He 178 fitted with the turbojet engine He S-3B first flew on 27 August 1939. This was the world's first aircraft to fly solely with turbojet power and it achieved a speed of 400 kmph (250 mph). The engine developed a static thrust of 4.9 kN (1100 lb) while running at a speed of 13,000 rpm and had a specific fuel consumption of 0.163 kg fuel per N (1.6 lb fuel per lb of thrust). The weight of the engine was 360 kg (795 lb).

Thus von Ohain achieved in a remarkably short time, the realization of the turbojet from concept to a working model and eventually into a flight engine leading to a successful first jet powered flight. His more rapid progress compared to Whittle, can in hindsight be perhaps attributed to a number of circumstantial factors. First his fortuitous choice of Heinkel whose enthusiasm and supply of financial and technical resources are in stark contrast to the difficulties faced by Whittle in getting his ideas accepted by a sceptical scientific bureaucracy which did precious little to help him try out his ideas. Another factor was that the Heinkel - Ohain project was a purely private enterprise and there were no cumbersome certification tests for the engine before clearance for flight trials, unlike the

Whittle engine. As mentioned above, the choice of a ready burning hydrogen as fuel helped von Ohain tremendously in getting a workable engine.

The third person who pioneered the turbojet propulsion plant was Herbert Wagner. By 1925 Wagner had established himself in the aeronautical field by his theoretical analysis of stress carrying thin metal sheets. This theory provided the basis for the design of monocoque aircraft structures which were vital in providing significantly improved structural strength and streamlining of designs. With his background in aircraft structures, aerodynamics and turbomachinery, he sought improved propulsion systems for high speed flights. While he was a Professor at Berlin University in 1934, he conceived of a turbo-prop propulsion system consisting of a gas turbine driving a propeller. In his performance estimation, he gave due consideration to the propulsive impulse due to the exhaust gases leaving the turbo-prop engine. In his parametric studies he varied the proportion of thrust delivered by the propeller and the exhaust jet and came to look upon the turbo-prop and turbojet as two extreme cases of this variation. He appreciated the necessity for high temperature materials to make the cycle workable and in particular, material for the turbine blade to withstand 850° C. He was convinced of the suitability of axial flow compressors and turbines for efficient engine configurations. He joined the Junkers Aircraft in 1935 and soon got the green signal from the company chairman to take up investigations in new types of propulsion systems, especially the turbo-prop. He was given a building and funds in the engine factory at Magdeburg for his activities. He brought his assistant, Max Adolf Muller from Berlin to Magdeburg where they initiated design studies leading to prototype construction. The design adopted for a turbojet had a five-stage axial flow compressor, a fully annular combustor and a two-stage axial flow turbine. The pressure ratio of the engine was 3:1, a remarkable feat for the time to achieve pressure ratio of 1.25 per stage. The engine was bench tested in 1938 and encountered severe components matching problems, some of which could be traced to the highly efficient but temperamental multistage compressor. It is interesting to recall that von Ohain had foreseen such a problem and had kept away from axial flow machines for his maiden venture. The Muller–Wagner engine became part of the German turbojet programme. It was later transferred to Heinkel by the German Air Ministry and its matching problems finally resolved by the end of 1942, but it did not enter any flight programmes.

The fourth person to be accredited with a major role in turbojet conceptualization and realization was Helmut Schelp. Schelp did his Masters degree at Stevens Institute of Technology, New Jersey in 1936 and thereafter returned to Germany. Here he carried out studies at the German Aeronautical Institute for Research (DVL) Berlin–Adlershof on the factors limiting the ultimate aircraft performance. His study indicated that compressibility could probably become a limiting factor at a flight Mach number of 0.82, which was well beyond the capability of any propeller to achieve. He carried out a systematic study of various potential power plants such as pulse jets, ram jets and turbojets. He concluded that the turbojet with low cross sectional area as is possible with axial flow machines would be the best solution. Thus Schelp by logical, analytical reasoning arrived at the turbojet configuration in the middle of 1937. Schelp came to occupy key positions in the RLM (the German Air Ministry) and channelized the development efforts of several German industries towards development of the turbojet engines for Germany.

In retrospect, it does appear very remarkable that four contemporaries, Whittle, von Ohain, Wagner and Schelp working independently and in ignorance of each other, hit upon virtually identical solutions of the turbojet at almost the same time. A solution to the problem perceived and deduced by each of them from the laws of physics, namely the limitations of the piston engine and propeller from achieving high flight speeds due to onset of compressibility effects and to devise practical systems, based on reaction principle for efficient propulsion at speeds comparable to the speed of sound. They conceived of the turbojet as the power plant which would have the necessary thrust-to-weight ratio and propulsive efficiency at speeds ranging from low to high subsonic and transonic ranges. They overcame the sceptics of their time with scientific arguments and practical demonstrations and started the turbojet revolution which has influenced the life of mankind in innumerable ways.

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